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Research Trends of Socio-Scientific Issues (SSI) in Bibliometric Analysis: Implications for Science Education (2010-2023)

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ABSTRACT Socio-Scientific Issues (SSI) are controversial social issues that are relevant to science and conceptually as well as procedurally related to science education. Although this approach has been widely used in science education, systematic studies that map its publication trends through bibliometric analysis remain very limited. This study analyzes research trends in the implementation of SSI in science education through bibliometric analysis of documents from the Scopus database for the period 2010–2023 using VOSviewer software. A total of 174 journal articles were analyzed through bibliometric mapping. The findings indicate that: (1) 2023 marked the peak year of publications with 33 documents; (2) the most popular keywords included socio-scientific issues, science education, science literacy, and education for sustainable development; (3) works by Kurup et al., Zidny et al., Puig et al., and Ottander & Simon were the most frequently cited; (4) Troy D. Sadler and Ingo Eilks were the most productive authors; and (5) the countries with the highest number of publications were the United States, Germany, and Turkey. This study provides valuable insights into research trends on SSI implementation in science education and offers directions for future research.

Keywords: Bibliometric analysis, Science education, Socio-scientific issues

1. INTRODUCTION

Education is a deliberate and planned effort to create a learning environment and process that supports students in actively developing their potential. It aims to equip them with spiritual strength, self-control, good character, intelligence, noble morals, and skills that are beneficial both for themselves and for society (Rahman et al., 2022). The development of technology and science continues to create new connections between society and science, often giving rise to complex and controversial issues. Many science teachers report that students' motivation and interest in learning science remain relatively low (Arika et al., 2021). One internal factor that can drive motivation to learn is students' interest in the subject matter itself (Dawson & Carson, 2020). In context-based learning, the learning process focuses on approaches that provide students with opportunities to understand science more deeply and relevantly. One of the themes in science education that has garnered significant attention in research is Socio-Scientific Issues (Arika et al., 2021).

Socio-Scientific Issues (SSI) are controversial social issues that are conceptually and/or procedurally connected to science (Sadler, 2009). The SSI approach incorporates real-world socio-scientific problems that are relevant, open for discussion, debatable, controversial, and scientifically related (Rahmawati et al., 2023). These issues are inherently open-ended, lacking clear solutions, and often present multiple plausible outcomes. While scientific principles, theories, and data provide valuable guidance, the decisions made are not solely based on scientific considerations. Various social factors, such as politics, economics, and ethics, also play a significant role in shaping these decisions. SSI can range from global challenges, such as climate change and genetic technology, to local issues, like addressing environmental concerns in a community or deciding the location for a new power plant. These characteristics make SSI a powerful framework for engaging learners in real-world problem-solving and interdisciplinary thinking (Sadler, 2011).

SSI provides an engaging platform for science learning experiences as it encompasses unstructured problems, where the available solutions are inherently complex and uncertain (Kuhn, 1991; Zohar & Nemet, 2002). Exploring these issues requires understanding and discussion of

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scientific concepts, principles, and practices within the context of open-ended questions (Kolstø, 2001). Unstructured problems, unlike those often encountered in science education, do not have a single correct answer and cannot be solved by relying solely on memorization or pre-learned answers. SSI often generates controversy, both due to its uncertain status and its connection to society. Issues that affect people's lives from different perspectives and interests spark attention and debate due to the social significance of these issues. Scientific data alone is insufficient to determine a solution, as decisions are also influenced by economic, social, political, or ethical factors. The influence of these factors in resolving an issue depends on the specific context of each problem (Sadler, 2009; Sadler & Zeidler, 2005). SSI is presented as a problem in which scientific knowledge and social awareness emerge in a mental conflict, requiring scientific literacy to make responsible decisions (Sadler & Zeidler, 2009).

The learning objectives of using SSI, according to Bayram-Jacobs et al. (2019), are: (1) students recognize the relationship between science and society; (2) students can question and evaluate evidence supporting scientific claims, analyze problems, and actions that may be taken by applying scientific knowledge, as well as develop opinions or decisions based on reasoning; (3) students can build arguments to express opinions using scientific knowledge, or critique others' arguments. According to Presley et al. (2013), learning through SSI is based on three fundamental aspects: (1) curriculum design, where SSI must be connected to the curriculum and allow for the application of knowledge gained from problem-solving to new situations; (2) students must play an active role and be open to reflecting on and understanding diverse perspectives; and (3) the characteristics of the educator and classroom environment, where the educator acts as a facilitator and the classroom environment fosters collaboration and mutual respect.

SSI has become an essential element in science education, aiming not only to teach students content knowledge but also to help them understand the characteristics of science and develop their skills in argumentation and decision-making (Schenk et al., 2021). Learning is a process of enhancing knowledge, but studying science provides a deeper understanding of the world. Science education plays a crucial role due to its relevance to human life and its ability to foster critical thinking and problem-solving skills that are universally applicable (Latif et al., 2020). The goal of science education is to offer students the opportunity to understand themselves and their environment through direct experience and inquiry (Osborne & Freyberg, 1985). On the other hand, it aims to equip students with knowledge and skills so they can apply them to make decisions and solve problems in everyday life, as science requires further skills and knowledge gained through experiments in the surrounding environment (Latif et al., 2020).

As far as we know, there has been no bibliometric study discussing the application of SSI in science education from 2010 to 2023. Therefore, this research is the first to conduct a bibliometric mapping analysis in this field. The period from 2010 to 2023 was chosen because it marks a significant development in the application of Socio-Scientific Issues (SSI) in science education, alongside growing attention to science literacy, Education for Sustainable Development (ESD), and 21st-century skills. Bibliometric analysis is a systematic approach to examining large bibliometric datasets to assess their impact on a specific field (Ferdaus et al., 2024). According to Ellegaard & Wallin (2015), bibliometric analysis is used to perform quantitative analysis on written publications. A bibliometric review provides a comprehensive overview of scientific output to identify research activity patterns over time and pinpoint the most influential authors and affiliations (Aria & Cuccurullo, 2017). Bibliometrics effectively provides data that can be utilized by policymakers, researchers, and other stakeholders to support the enhancement of research quality (Nandiyanto et al., 2020).

Based on the explanation above, the aim of this study is to analyze the application and research trends of SSI in science education from 2010 to 2023 through bibliometric mapping of distribution in the Scopus database using the VOSviewer software. The goal of bibliometric analysis is to provide an in-depth understanding of various academic disciplines, as well as to map publication trends and the contribution of articles to the advancement of knowledge (Guo et al., 2019; Yulianingsih et al., 2020). Through this analysis, it is expected to gain insights into research innovations and trends, which will help researchers and educators identify areas that still require further investigation for future knowledge development (Dwikoranto et al., 2023). The Research Question (RQ) that guides this study is presented as follows:

RQ1: How many publications were published from 2010 to 2023 related to SSI in science education?
RQ2: What are the most commonly used keywords by authors in research on the application of SSI in science education?
RQ3: Which research documents have been cited the most by authors?
RQ4: Who are the top ten most productive authors with the highest number of publications on the application of SSI in science education?
RQ5: How are the distribution of publication mapping and the relationship between countries in research related to SSI in science education?

2. METHOD

2.1 Study Design

The design of this research study is a bibliometric analysis aimed at understanding the evolution of the application of Socio-Scientific Issues (SSI) in science education. According to Pritchard (1969) in Phoong et al. (2022), bibliometric analysis is a statistical study of various materials that have been published, such as books or articles. Bibliometric analysis is considered a part of scientometrics, which uses mathematical and statistical methods to evaluate scientific activity in a particular field of research (Aparicio et al., 2019). The object of our research is the application of SSI in science education. In this bibliometric analysis, we followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to present a comprehensive literature review on the application of SSI in science education. According to Liberati et al. (2009), when conducting bibliometric mapping analysis using the PRISMA procedure, the steps include: Identification, Screening, Eligibility, and Inclusion. This procedure is applied to minimize bias and present findings transparently and credibly. The following is a diagram of the PRISMA procedure in this study.

2.2 Procedure

The documents used in this study were sourced from the Scopus database (https://www.scopus.com/) on Wednesday, November 20, 2024. Using the advanced search function, the search string included a combination of compound keywords joined by OR and AND operators. The search query was as follows: (TITLE-ABS-KEY ("socio scientific issues") OR TITLE-ABS-KEY ("socio-scientific issues") OR TITLE-ABS-KEY ("socioscientific issues") AND TITLE-ABS-KEY (science) AND TITLE-ABS-KEY (education)). The inclusion criteria encompassed documents containing at least one of the keywords in the title, abstract, or keywords. The variables analyzed included publication year, keywords used, cited documents, cited authors, country relationships, and open access. We then collected the frequency of each variable. To map trends in this field, the indices were analyzed quantitatively.

No specific time limits were applied during the search process. The bibliometric analysis includes documents published throughout the years. The number of articles began to rise in 2009, from 1 to 4 documents, and remained consistent at 5 documents in 2010 and 2011. Therefore, the data collection period for this study spans from 2010 to

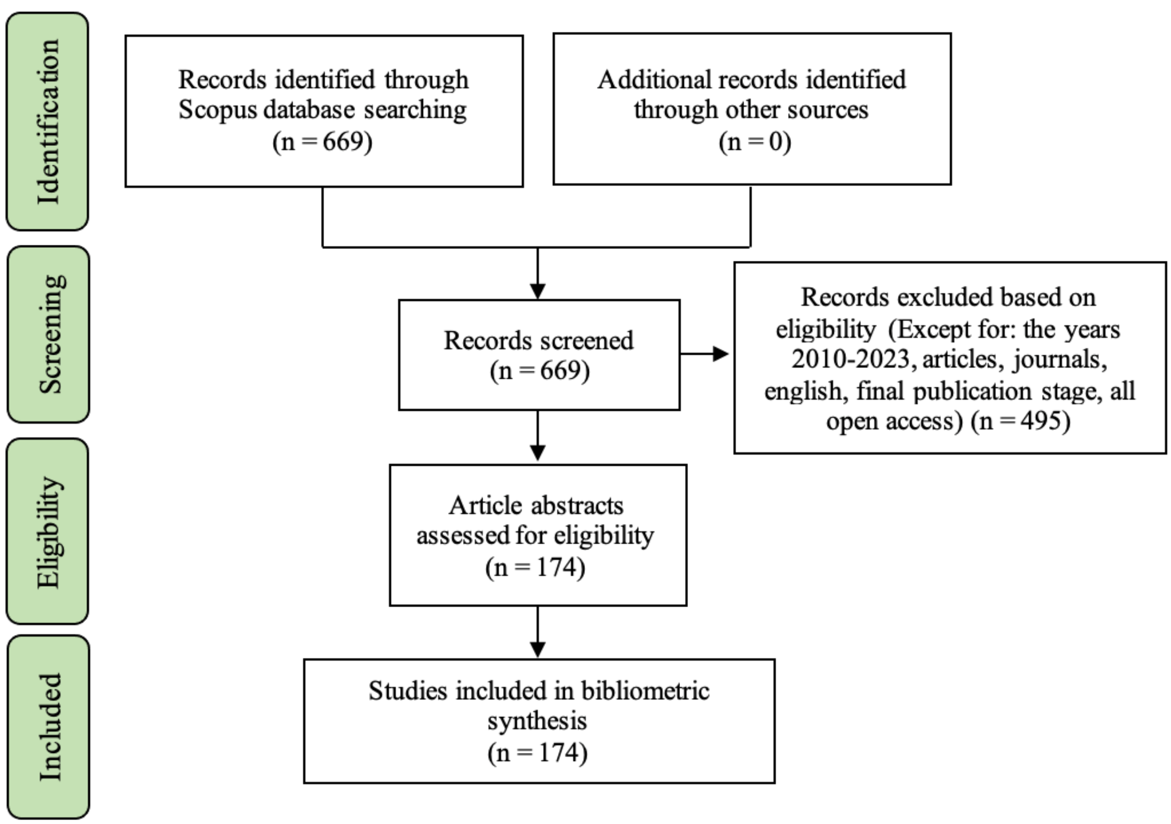

Figure 1 PRISMA Flow Diagram

2023, covering a 14-year interval (2010-2023). After the initial search, a total of 669 documents were accessed from the inception of the topic up to 2024. For this review, only journal articles were selected. Other document types were excluded from the study. We used the Scopus filter to remove 495 irrelevant works. After eliminating works that did not align with the research goals, a total of 174 relevant articles were extracted. From the selected articles, data including citation information, bibliographies, abstracts, and keywords were downloaded in .csv format. The data was then uploaded into the VOSviewer software for further analysis.

2.3 Data Analysis

To answer the research questions, data analysis was conducted. Bibliometric and descriptive analysis of the Scopus database was applied to determine publication trends related to the application of SSI in science education. The researcher used Microsoft Excel to identify publication trends over the last 14 years with tables and graphs. For citation trends, the h-index of the published works was determined using the Scopus database. Keyword trend analysis related to the application of SSI in science education was performed to determine research focus. The research focus can be identified from keywords visualized by the VOSviewer software. VOSviewer was used to create network visualizations showing relationships between countries, keywords, and authors. VOSviewer is a widely used computer software, employed in this study to collect, analyze, and visualize bibliographic elements. It was chosen for this study because of its frequent use in publications applying bibliometric analysis (Irwanto et al., 2023; van Eck & Waltman, 2010).

3. RESULT

3.1 RQ1: How many publications were published from 2010 to 2023 related to SSI in science education?

The distribution of publications over the past 14 years, as shown in Figure 2, covers the period from 2010 to 2023, resulting in a total of 174 documents. The peak in publications occurred in 2021, with 33 documents, accounting for 18.97%. Meanwhile, publications in 2022 and 2023 reached 13.79% and 18.39%, respectively. A significant surge in publications is evident between 2020 and 2021, where the number of articles published increased from 22 to 33. This indicates a significant rise in publications in 2021 compared to the previous year, reflecting growing interest in or the increasing importance of SSI in science education. The sharp rise in publications from 2020 to 2021 marks a major shift in the application of SSI in science education. This suggests that SSI is gaining more attention in the educational field, possibly due to increased awareness of its role in enhancing environmental knowledge, science literacy, critical thinking skills, and student motivation by engaging with relevant social issues. Additionally, the integration of SSI in the curriculum might also respond to the demand for 21st-century skills, outlining the key competencies required for lifelong learning for all individuals, including educators and students (Mardhiyah et al., 2021). These include the 4Cs: Communication, Collaboration, Critical Thinking, and Creativity (Dewi et al., 2023). To better understand the strength and sustainability of this trend, further research and monitoring are needed. However, it is important to note that the lowest number of publications occurred in 2016, with only two publications recorded.

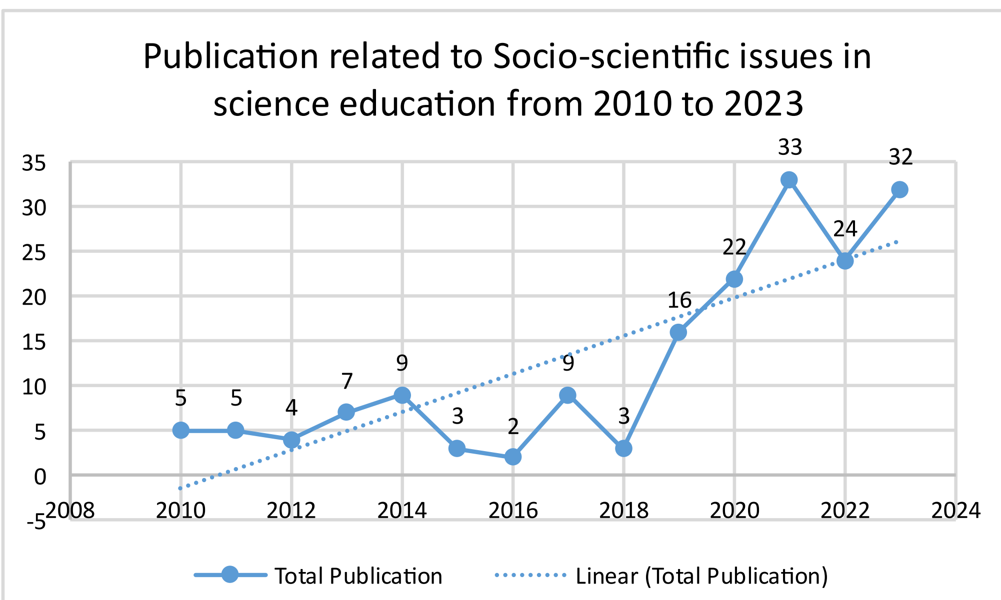

Figure 2 Publications from 2010 to 2023

3.2 RQ2: What are the most commonly used keywords by authors in research on the application of SSI in science education?

Keyword analysis was performed to identify the research focus related to the application of SSI in science education. As a result of this analysis, the initial set of 50 keywords was simplified to 15 keywords.

The network visualization in Figure 3 shows five clusters that encompass 15 keywords related to SSI in science education. The first cluster (red) is the largest, consisting of five keywords: "biology education, inquiry-based learning, motivation, socio-scientific issues, teacher education". The keyword "socio-scientific issues" has the largest node, indicating it is the most frequently used by authors and is connected to all the other keywords. The second cluster (green) includes three keywords: "climate change, critical thinking, environmental education". In this cluster, "climate change" has the largest node, suggesting it is the most frequently used. The third cluster (dark blue) consists of three keywords: "knowledge, science education, and student". Here, "science education" has the largest node, indicating it is the most frequently used. The fourth cluster (yellow) contains two keywords: "context-based learning and education for sustainable development". In this cluster, "education for sustainable development" has a larger node than "context-based learning", showing it is more frequently used. The fifth cluster (purple) contains two keywords: "argumentation and science literacy". These keywords have nearly the same node size, indicating they are frequently used together in research.

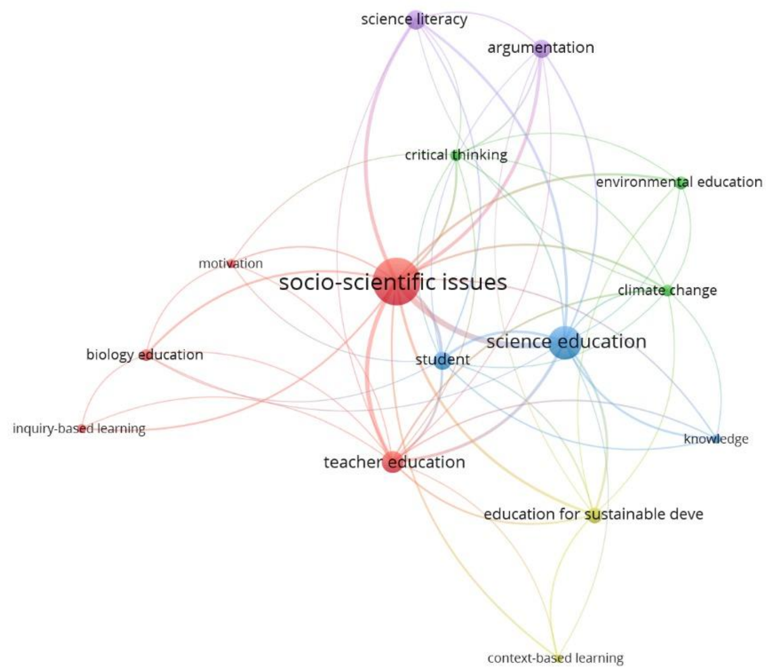

Figure 3 Keyword Co-Occurrence Network (Occurrence Threshold ≥ 3)

3.3 RQ3: Which research documents have been cited the most by authors?

The publication statistics related to the application of SSI in science education over the past 14 years show an increase in the number of publications from 2020 to 2021, peaking at 33 publications in 2021. SSI has increasingly been used in education research (Tekin et al., 2016) and has become an essential component of science education (Schenk et al., 2021). In 2021, 33 articles were published, and all have been cited at least once. Below is a list of the top 15 most-cited journals.

The publication in 2021 with the highest number of citations is the study by Kurup, P. M., 2021, which discusses decision-making based on information regarding global warming and climate change in the context of SSI among secondary school students in the UK, with a total of 29 citations. The second position is held by Zidny, R., 2021, whose research explores indigenous knowledge to identify content and context in science learning to support Education for Sustainable Development (ESD), with a total of 43 citations. Of the 33 articles discussing the application of SSI in science education, SSI was found to be applied at almost all educational levels, ranging from secondary schools to universities.

3.4 RQ4: Who are the top ten most productive authors with the highest number of publications on the application of SSI in science education?

Information about the 10 most productive authors with the highest number of publications related to the

Table 1 List of Documents Published in 2021 with at Least One Citation

No.	Author	Title	Journal	Citation
1.	Kurup *et al.*, 2021	Informed-Decision Regarding Global Warming and Climate Change Among High School Students in the United Kingdom	Canadian Journal of Science, Mathematics and Technology Education	29
2.	Zidny *et al.*, 2021	Exploring indigenous science to identify contents and contexts for science learning in order to promote education for sustainable development	Education Sciences	22
3.	Puig *et al.*, 2021	"Fake News" or Real Science? Critical Thinking to Assess Information on COVID-19	Frontiers in Education	20
4.	Ottander & Simon, 2021	Learning democratic participation? Meaning-making in discussion of socioscientific issues in science education	International Journal of Science Education	16
5.	García-Carmona, 2021	Learning about the nature of science through the critical and reflective reading of news on the COVID-19 pandemic	Cultural Studies of Science Education	15
6.	Schenk *et al.*, 2021	Socioscientific Issues in Science Education: An opportunity to Incorporate Education about Risk and Risk Analysis?	Risk Analysis	15
7.	Dauer *et al.*, 2021	Students' Civic Engagement Self-Efficacy Varies Across Socioscientific Issues Contexts	Frontiers in Education	15
8.	Susilawati *et al.*, 2021	Socio-scientific issues as a vehicle to promote soft skills and environmental awareness	European Journal of Educational Research	15
9.	Beniermann *et al.*, 2021	Reasoning on controversial science issues in science education and science communication	Education Sciences	12
10.	Romero-Ariza *et al.*, 2021	Changing teachers' self-efficacy, beliefs and practices through STEAM teacher professional development (Cambios en la autoeficacia, creencias y prácticas docentes en la formación STEAM de profesorado)	Infancia y Aprendizaje	12
11.	Martini *et al.*, 2021	Improving undergraduate science education students' argumentation skills through debates on socioscientific issues	Jurnal Pendidikan IPA	11
12.	Hogan & O'Flaherty, 2021	Addressing education for sustainable development in the teaching of science: the case of a biological sciences teacher education program	Sustainability (Switzerland)	10
13.	Solli, 2021	Appeals to Science: Recirculation of Online Claims in Socioscientific Reasoning	Research in Science Education	9
14.	Alcaraz-Dominguez & Barajas, 2021	Conceiving socioscientific issues in stem lessons from science education research and practice	Education Sciences	9
15.	Wahono *et al.*, 2021	Teaching socio-scientific issues through integrated STEM education: an effective practical averment from Indonesian science lessons	International Journal of Science Education	9

Table 2 Number of Publications by the Top 10 Authors

No.	Author	Institution	Country	N	*H-Index*
1.	Ingo Eilks	University of Bremen	Germany	11	30
2.	Troy D. Sadler	The University of North Carolina at Chapel Hill	United States	6	43
3.	Anne Solli	University of Gothenburg	Swedia	4	6
4.	Benjamin C. Herman	Texas A&M University	United States	3	16
5.	Li Ke	University of Nevada	United States	3	7
6.	Åsa Mäkitalo	University of Oslo	Norwegia	3	15
7.	Safwatun Nida	Universitas Negeri Malang	Indonesia	3	5
8.	Robby Zidny	University of Sultan Ageng Tirtayasa	Indonesia	3	5
9.	Dana L. Zeidler	University of South Florida	United States	3	35
10.	Tali Tal	Technion - Israel Institute of Technology	Israel	3	25

application of SSI in science education is presented in Table 2.

In Table 2, it can be observed that the author with the highest number of publications is Ingo Eilks, with eleven articles, followed by Troy D. Sadler with five articles, and Anne Solli with four articles. Additionally, Benjamin C. Herman, Li Ke, Åsa Mäkitalo, Safwatun Nida, Robby Zidny, Dana L. Zeidler, and Tali Tal each have 3 articles.

The most productive authors based on their h-index include Troy D. Sadler (h-index = 43), Dana L. Zeidler (35), and Ingo Eilks (30). The h-index is a metric that measures both the productivity and impact of a researcher's published works in the Scopus database (Hirsch, 2005). Overall, the authors included in this analysis have each contributed a minimum of three articles.

This section analyzes the collaboration network of authors in the database, focusing on those with at least two articles, resulting in a total of 49 authors involved. Figure 4 illustrates the entire collaboration network, comprising 21 clusters, each represented by a distinct color. The clusters vary in size, with most remaining isolated from one another. Larger nodes indicate authors with a higher number of articles (Irwanto et al., 2023). The first cluster (red) is the largest, consisting of seven authors, including Herman, who is closely connected to Ke, Oertli, Owens, Sadler, Zangori, and Zeidler. The second cluster (green) includes six authors: Arvanitis, Haglund, Hamza, Lundegård, Schenk, and Wojcik. The third cluster (blue) features five authors: Eilks, Marks, Nida, Rahayu, and Zidny. The fourth cluster (yellow) has four authors: Chu, Kim, Mang, and Martin. The fifth cluster (purple) contains three authors: Chang, Irwanto, and Wahono. Bibliometric data reveal one cluster with seven authors, one with six authors, one with five authors, one with four authors, three clusters with three authors, four clusters with two authors, and ten clusters with one author each. This indicates that collaboration among SSI researchers in science education remains relatively weak, with most studies conducted within small groups of one to seven authors.

3.5 RQ5: How is the distribution of publication mapping and the relationship between countries in research related to SSI in science education?

There are 15 countries with at least 4 documents. Figure 5 shows the relationships between countries, with Germany having the most connections, as evidenced by the number of relationships it has. Sweden has a nearly equal number of connections to Germany. Several countries, including the United Kingdom, Switzerland, Brazil, and the United States, have direct connections with Sweden. This indicates that Germany and Sweden have established collaboration networks with several other countries. Canada, Israel, and Spain have the fewest connections, with only one relationship each: Canada and Israel are directly connected to the United States, while Spain is connected to Germany. Indonesia has direct connections with Germany and Australia. Among these 15 countries, there are 5 clusters, with the largest cluster marked by a red circle, consisting of Canada, Israel, Turkey, and the United States. Other clusters are marked in different colors, such as blue, green, yellow, and purple.

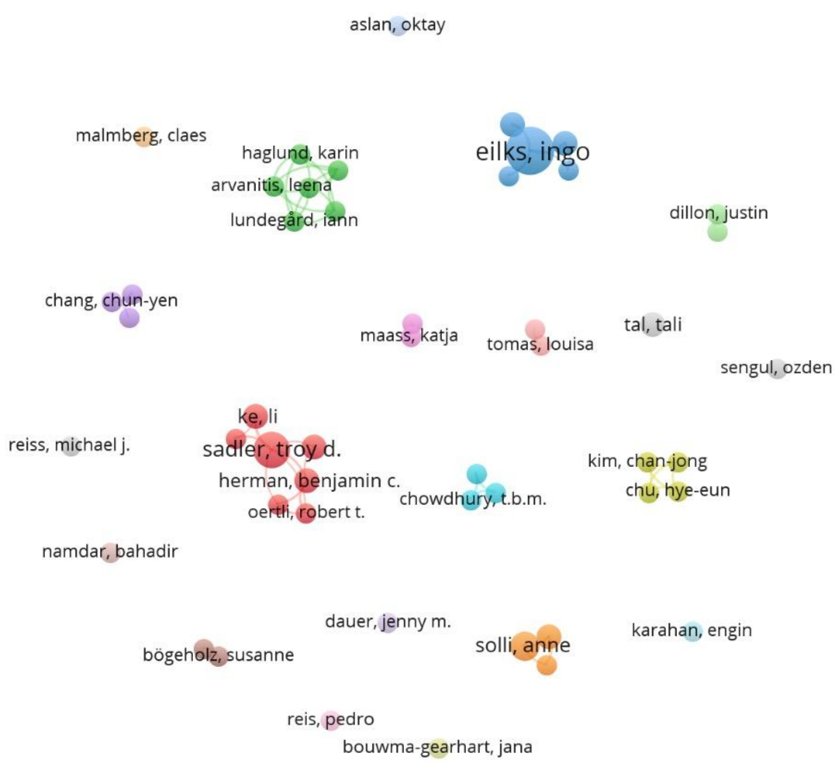

Figure 4 Collaboration Network of Authors

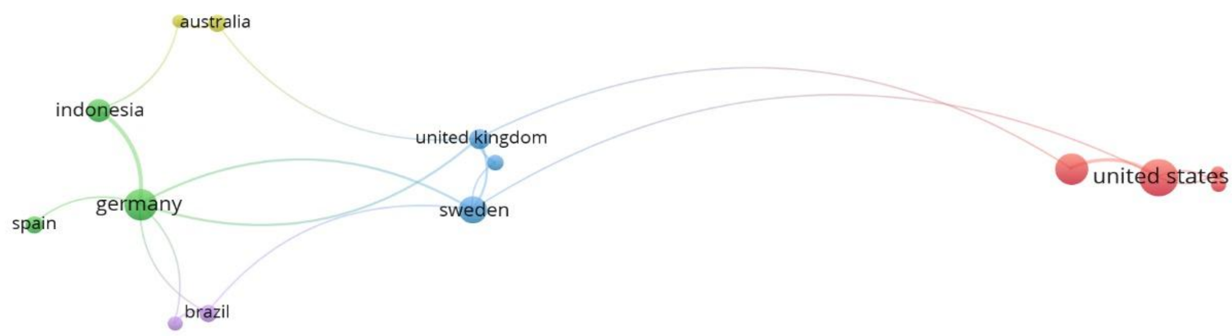

Figure 5 The Collaboration between Countries Discussion

4. DISCUSSION

In this study, we utilized the Scopus database to analyze publication trends on the application of SSI in science education over the last 14 years (2010-2023). This bibliometric review provides in-depth insights into previous research and offers possible directions for further studies in this field. The analysis results indicate a rise in the number of articles related to the application of SSI in science education, reflecting the growing interest in this field from 2010 to 2023. According to Tekin et al. (2016), trends related to SSI have been increasing in recent years. Further research on SSI-related topics is expected to continue developing within the realm of science education in the coming years. Therefore, it can be concluded that the number of publications on the application of SSI in science education has significantly increased. This aligns with the findings of Tekin et al. (2016), that articles related to SSI continue to rise. The number of publications in 2023 and beyond is expected to keep growing over time. As visualized in Figure 2, the number of publications in 2023 is much higher compared to 2010. Thus, this finding confirms Price's Law, which states that scientific output tends to double every 10 years (Price, 1986). SSI has increasingly been used in science education research (Tekin et al., 2016) and has become an important part of science education (Schenk et al., 2021).

The bibliometric analysis involving 174 documents shows that "socio-scientific issues" is the most commonly used keyword. Other important terms such as "science education," "teacher education," "science literacy," "argumentation," "education for sustainable development," "environmental education," and "climate change" also emerged in this research. This is consistent with previous studies, such as those by Ban & Mahmud (2023), Falah et al. (2024), and Tang et al. (2024). It can be concluded that these keywords have a stronger relationship and impact, highlighting current research topics in SSI within science education. Author keywords are considered important to analyze in this study because they generally reflect the content of the papers written by the author (Comerio & Strozzi, 2019). As pointed out by Wen & Huang (2012), author keyword analysis is essential for assessing how research topics have evolved over time.

Research trends in this field have become a major focus among scientists over the past 14 years. Based on the annual distribution, the documents with the highest citation counts are concentrated in 2021. The article with the highest citation counts to date is by Kurup et al. (2021), with 29 citations. This is followed by articles from Zidny et al. (2021), Puig et al. (2021), and Ottander & Simon (2021) with 22, 20, and 16 citations, respectively. It can be stated that the article by Kurup et al. (2021) has had a significant impact on SSI research over the past 14 years. As mentioned by Aksnes et al. (2019), the more an article is cited, the greater the impact of the research. In other words, articles that are frequently cited indicate that the work has a substantial influence in its field. Authors are measured by their h-index, which is an index that assesses the productivity and impact of researchers' works published in the Scopus database (Hirsch, 2005). The authors who stand out the most in terms of h-index are Troy D. Sadler (h-index = 43), Dana L. Zeidler (35), and Ingo Eilks (30). Overall, these authors have published at least three articles.

The authors with the highest number of publications related to the application of SSI in science education are Ingo Eilks (11 articles), Troy D. Sadler (6 articles), and Anne Solli (4 articles). Seven other authors each contributed three articles. Prof. Dr. Ingo Eilks of the University of Bremen, Germany, has extensively published on socio-scientific issues, science education, chemistry education, and Education for Sustainable Development (ESD) in leading journals. Among countries, the United States, Germany, and Turkey rank highest in article production, reflecting significant interest in the topic. Germany's researchers have made substantial contributions to advancing SSI research in science education. Through DAAD, Germany provides research funding for doctoral and postdoctoral researchers at universities or research institutions in Germany. The funding includes monthly stipends, health insurance, travel allowances, research support, and more. The program aims to foster international collaboration and advance research potential. Given this, it is unsurprising that Germany is one of the leading contributors to this field. Researchers from developed countries like Germany produce a significant number of publications on SSI in science education, highlighting Germany's crucial role in fostering scientific collaboration worldwide.

5. CONCLUSION

This bibliometric review provides a comprehensive overview of the development of publications on the application of SSI in science education from 2010 to 2023. The first search in the Scopus database retrieved 669 documents, which were narrowed down to 174. The analysis shows that most of the publications are focused on 2023, with a rapid increase, reaching 33 documents. The most popular keywords used by authors in the field include "socio-scientific issues," "science education," "teacher education," "science literacy," "argumentation," "education for sustainable development," "environmental education," and "climate change." The most cited document is by Kurup et al. (2021), with 29 citations, followed by Zidny et al. (2021), Puig et al. (2021), and Ottander & Simon (2021) with 22, 20, and 16 citations, respectively. The authors with the most publications on SSI in science education are Ingo Eilks (11 articles), Troy D. Sadler (6), and Anne Solli (4). The most productive authors are Troy D. Sadler, Dana L. Zeidler, and Ingo Eilks. The author with the most citations is Kurup et al. (2021), from Germany. Germany is the country with the most connections with other countries and ranks second after the United States in article production.

This study has several limitations, as reported in previous literature, Ban & Mahmud (2023), and Falah et al. (2024). First, we only utilized bibliographic data from one database, Scopus, which may not cover all publications related to the application of SSI in science education. Future researchers could replicate this study using other databases like WoS, ScienceDirect, and Google Scholar. This research includes only journal articles, so future studies could explore SSI trends in science education through other documents, such as books, book chapters, review journals, and conference reviews. Nonetheless, we believe our review provides an up-to-date status and development of SSI in science education, offering important insights for policymakers and educators in implementing SSI in teaching and learning processes. Additionally, this paper suggests directions for future research in this field.

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